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Overall review of pumped-hydro energy storage in China: Status quo, operation mechanism and policy barriers

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A R T I C L E   I N F O

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A B S T R A C T

With the integration of increased variable renewable energy generation and advent of liberalized electricity market, much attention has been devoted on the development of pumped hydro energy storage (PHES) as it has many prominent advantages of ensuring the safe and steady operation of power grid. In China, PHES has met a booming periods for the last ten years. Currently, there are 24 PHES stations with an installed capacity of 16.95 GW while government's target of 2020 is 50.02 GW. In this paper we provide an overall review of China's PHES development with a detailed presentation of the installed capacity and distribution of existing and proposed PHES stations, examine 4 typical stations in order to give a good description for the practical functions of PHES in power grid, analyze the management mode and price mechanism of PHES operation and point out the barriers in PHES development in China. State Grid Corporation of China (SGCC), which are making great efforts on China's PHES development, is discussed as a role model. On that basis we suggest PHES in the fast developing period should be temporarily operated and scheduled by grid companies in terms of exertion of its positive effects, while government should also take responsibility to subsidize on the stations' operation to relieve the price pressure of the ever-growing integration of renewable energy.

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1. Introduction

PHES is currently the only operationally available large scale energy storage technology. The basic principle of PHES is to utilize attitude intercept to store electric energy. The plant pumps water in a reservoir in low-price periods, working as a load, and then discharging the stored water during high-price periods, operating then as hydraulic generator.

With the increasing penetration of renewable energy and customers' growing demand on the stability of power grid operation, PHES is playing a very important role in power system in many countries. In recent years, there has been a flurry of commercial interest in PHES worldwide. There are over 300 PHES stations operating with total capacity of 95 GW, and the predictive installed capacity of 2015 will come up to 188 GW [1]. In the United State, there are 40 PHES stations with a total capacity of $\sim$20 GW [2]. As of 2009, the European Union has an installed capacity of 36 GW accounting for 4.3% of total generating capacity within the region [3]. Within Japan there is currently approximate 25.5 GW installed capacity accounting for 10.99% of its domestic total capacity [4]. In Turkey, PHES has become one of the most important system in meeting the fast growing wind power generation [5]. The prospect of German's PHES has improved even though profitability remains a major challenge. The government aimed to increase the available capacity by up to 60% [6].

The advantages of PHES to power system are systematically documented in literatures [7–10] and can be summarized as follows.

- Supply energy in times of high demand and allow base load power plants (such as coal plant and nuclear plant) to operate at high efficiencies in periods of low demand.
- The flexible generation of PHES can provide both up and down regulation, which could stabilize the intermittent output of renewable energy resources in the power system.
- The quick start capacity of PHES makes it suitable for black stars and provision of spinning and standing reserve.
- Act as fast response peaking plant to complement high inertia nuclear power and as an integrator for variable wind/solar power.

As the case of China, PHES also have enjoyed a booming development in the last 10 years, although a lot of problems also occurred on the aspects of management mode and electricity pricing mechanism. There is some lack of knowledge about the status quo of China's PHES development, and the study on the operation mechanism and policy is also inefficient. So we conducted this study to present an overall review on PHES development in China and provided our perspectives on how to meet the challenges as we analyzed the mechanisms and policies.

This paper is structured as follows: Section 2 gives an overview of history, status quo and trend of PHES in China, and then reviews the technical and operational characteristics of several typical PHES stations; Section 3 examines current management and price mechanisms of PHES based on the analysis of each mechanism's advantage and weakness; Section 4 analyzes the policy bottleneck and some challenges of PHES in China and then makes suggestions in the end. Section 5 concludes with observations on current trends.

2. History, status quo and trend of PHES development

2.1. Historical PHES development

The development of PHES is relatively late in China. In 1968, the first PHES plant was put into operation in Gangnan (in north China), with a capacity of 11 MW. Five years later, the construction of another PHES plant was completed in Miyun (in north China), with an installed capacity of 22 MW. Both of the two stations are pump-back PHES which uses a combination of pumped water and natural inflow to produce power. Since then, the construction of PHES station has largely been dormant until 1990s. In 1993, Panjiakou (in north China) PHES station, the first pure PHES in China (rely entirely on water that has been pumped to an upper reservoir from a lower reservoir) was built with an installed capacity of 42 MW.

In 2002, regulators of China started restructuring the power sector, which result in a transition from vertically integrated power system into competitive wholesale markets that separated generation and transmission. In the earlier stage of restructuring, it was not clear who was qualified to participate into the construction and operation process of PHES. In 2004, government stipulated that the construction and operation of PHES station, in principle, should be taken by grid company.

During the first 10 years of 21st century, the step of PHES construction in China was on a high speed. Fig. 1 and Table 1 respectively shows the data of existing PHES capacity and the capacity under construction from 2004 to 2010.

A number of key drivers for the development of China's PHES can be summarized as follows.

- Governmental and regional targets for carbon reduction have been stimulating the integration of renewable energy for years. The rapid development of wind energy in north and west China can be considered as the prime drivers for increased PHES development. (In 2010, the total installed wind power capacity is 44.7 GW, of which 42.4% has not connected to the grid [11]).
- Electricity consumption has been growing with China's rapid development of industry, which makes the PHES badly in need to compromise the valley-to-peak gap.
- Since the security of electric power supply has been emphasized by regulators, PHES need to be widely used to contribute to the reliability of power grid as it can provide ancillary services.

2.2. Current situation of PHES

2.2.1. Capacity of PHES and its distribution

In 2010, there has been 24 PHES stations established nationwide, with a total capacity of 16.95 GW. Meanwhile, 14 stations,

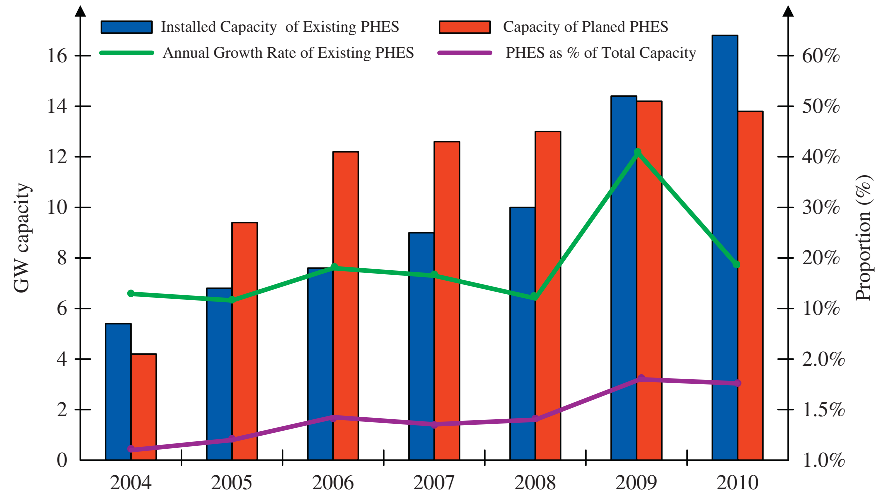

Fig. 1. Data of the development of PHES in China from 2004 to 2010.

Table 1
Data of the development of PHES in China from 2004 to 2010.

	2004	2005	2006	2007	2008	2009	2010
Installed capacity (GW)	5.701	6.421	7.645	8.945	10.086	14.250	16.952
Proportion of total installed capacity (%)	1.17	1.20	1.30	1.28	1.32	1.79	1.78
Number of plant in operation	10	12	14	15	17	20	24
Annual rate of growth (%)	13.65	12.63	19.06	17.00	12.76	41.28	18.95
Capacity under construction (GW)	4.200	9.300	12.260	12.600	13.150	14.140	13.840
Number of plant under construction	7	9	13	14	15	14	14

with capacity of 13.84 GW, are under construction [12]. Fig. 2 shows the locations of all PHES plants. Most of PHES stations are named according to the name of the city or county where the PHES facility located.

From Fig. 2, we can see that the majority of PHES were built in North, East and Central China, where the total electricity consumption and peak power load are relatively high. Only two PHES facilities, Yangzhuoyong lake (with 90 MW) in Tibet and Baishan (with 300 MW) in Jilin province, are separately operating in Northwest China and Northeast China. In South China, only two PHES are currently put into operation (Guangzhou and Huizhou PHES station) while five stations are still under construction in Guangdong and Fujian province. The specific information of PHES in each region of China can be seen in Fig. 3 and Table 2. It should be noted that all the data and information presented in Figs. 1–3 and Tables 1–3 are based on statistics from government or power grid company as showed in [12–18].

2.2.2. *Presentation of typical PHES stations*

The functions of PHES can be seen in this section as we introduce 4 significant PHES stations. There are two reasons to pick these stations. First, all the stations were operated in high-load power grids, making it available for the stations to play their full performance; second, the 4 stations are rich in data and relative statistics can be easily obtained as these stations have been operated for years. Panjiakou and Shisanling stations are presented together as they are connected in a same power grid.

(1). Panjiakou and Shisanling PHES station
Panjiakou station (270 MW) and Shisanling station (800 MW) were built in the early 1990s [19,20]. We introduce the two stations together because both of the stations are connected into Jingjintang grid, which is power-dominated by thermal plants. Before the two stations were put into operation, coal-fired plants were 100 percent used in Jingjintang grid to undertake the power following task. However, the power output can hardly accommodate with power load with the limitation of thermal units. Since the two stations put into construction, power supply condition has largely been improved, with the qualified cycle-frequency-rate up to 99.9%. Furthermore, the two stations also served as emergency reserve for the grid. For instance, in June 2010, rainy and foggy weather lasted for more than ten days, making weak transmission lines continue to trip. During that time, Shisanling station quickly reacted to the emergency by making 48 urgent restart schemes with no mistake [20].

(2). Tianhuangping PHES station
Tianhuangping station, completed in 2000, has an installed capacity of 1800 MW. The storage capacity of its upper reservoir is 10.46 TWh, and its daily generation is 8.66 TWh. Located in Anhui province, which is near the load center of East China (175 km from Shanghai, 180 km from Nanjing, 57 km from Hangzhou), the station plays a significant role for the stable operation of East China grid. During 2005–2009, Tianhuangping has already reacted as an imperative frequency adjustment tool and emergency reserve for 33 times [21]. It also reacted as a blackout start power station to serve for the recovery of power grid in the time of system breakdown.

(3). Guangzhou PHES station
Guangzhou station is the largest PHES station in China, with an installed capacity of 2400 MW. As a auxiliary project of Daya Bay Nuclear Power Plant, the purpose of the station, in the first place, is to ensure the long-term operation of both the nuclear power plant and Guangdong power grid from the aspect of steady power supply and secure operation of power

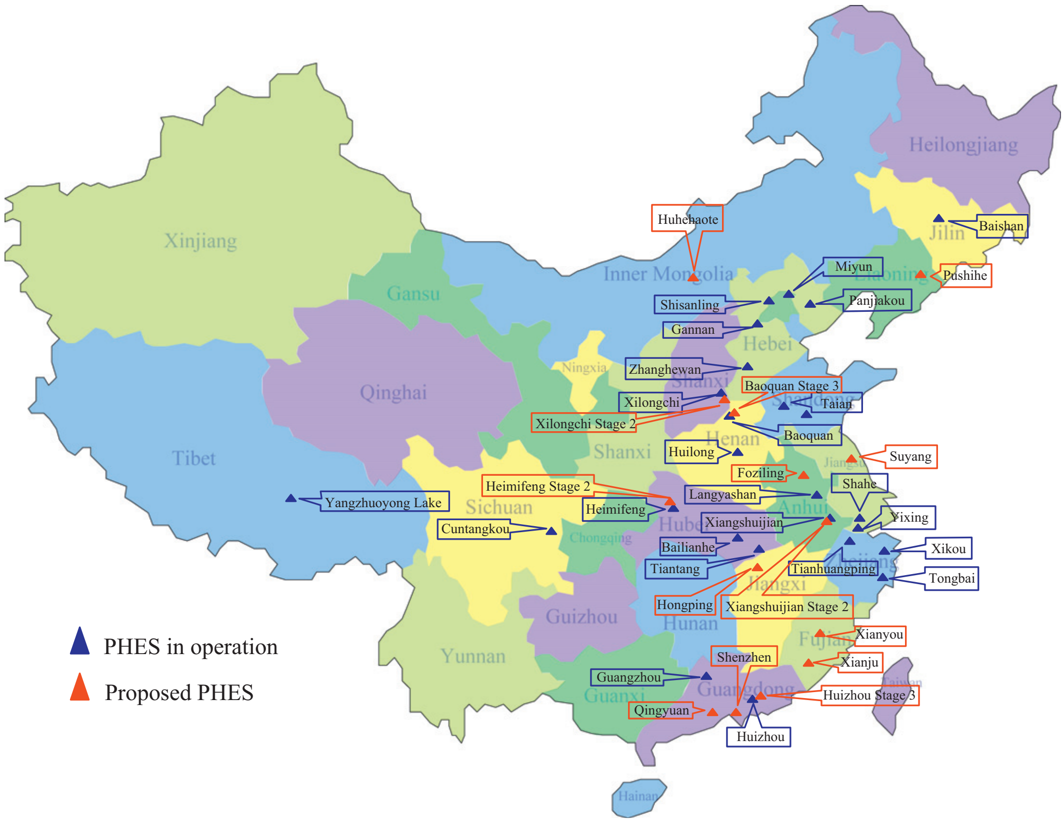

Fig. 2. Locations of existing PHES station and PHES under construction.

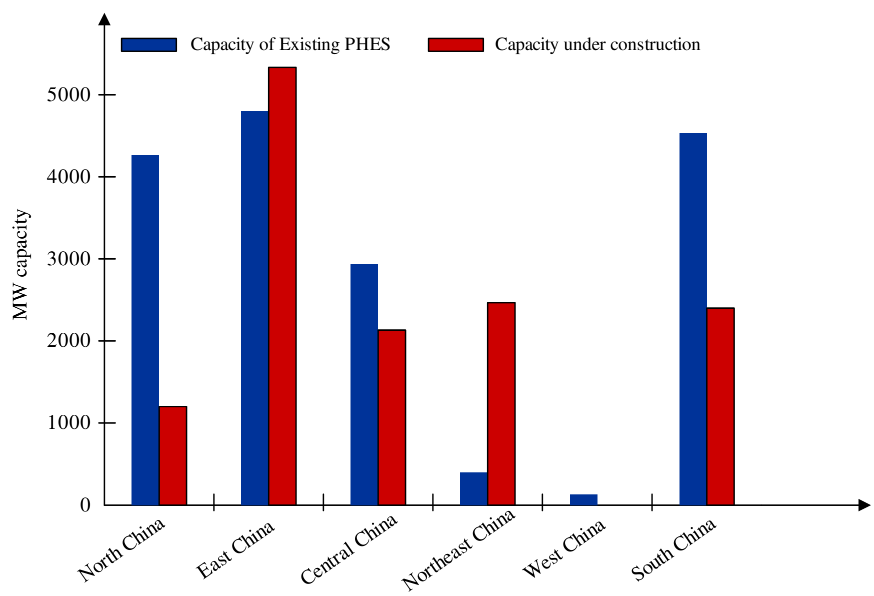

Fig. 3. Data of PHES capacity in each region of China.

grid. Statistics show that phasing operation time of the station is 1100 h from 2004 to 2008, especially during spring festival and National Day. Since 2000, Guangzhou station has urgently operated 116 times to cope with system emergency. Meanwhile, Guangzhou station also had economic advantage compared to other kind of power peaking plants. Statistics of CLP Power Hang Kong shows that the cost of fuel-based generation is generally 1.88 times than Guangzhou PHES station, while gas-based generation is 3.88 times [22].

Guangzhou PHES station is also a good example of leasing-pattern. At the beginning of the construction, technical equipments and capital was in short supply. The construction funds was raised and supported by CLP Power Hong Kong. When the construction completed, half of the capacity of plant A (one plant of Guangzhou PHES station with 1200 MW capacity) was rented by CLP Power Hong Kong, while another half was jointly rented by Guangdong power grid Corporation and CGNPC. Plant B (also 1200 MW) was totally rented by Guangdong power grid Corporation [23].

Table 2
Data of PHES capacity in each region of China (MW).

	North China	East China	Central China	Northeast China	West China	South China
Total MW capacity	5503	10,220	4992	2700	90	7280
Existing MW capacity	4303	4860	2892	300	90	4500
Number of existing plant	7	7	6	1	1	2
MW under construction	1200	5360	2100	2400	0	2780
Number in construction	1	5	3	2	0	3

Table 3
Planned capacity of PHES in 2015 and 2020 (MW).

	Existing capacity (MW) in 2010	Addition (GW)		Accumulation (GW)	
		2011–2015	2016–2020	2015	2020
North China	4303	2.88	3.03	7.18	10.21
East China	4860	6.30	4.00	11.16	15.16
Central China	2892	2.90	2.50	5.79	8.29
Northeast China	300	2.40	1.10	2.70	3.80
West China	90	0.75	1.62	0.84	2.46
South China	4500	1.50	4.10	6.00	10.10
Overall capacity	16,945	16.72	16.35	33.67	50.02

2.3. Development tendency of PHES in China

Data in Table 1 suggests that the capacity of PHES and its number have been increased for years, especially in 2009 when the annual growth rate was 41.28%. However, the proportion of PHES in total installed capacity has kept low (under 2%). Scholars in Japan used to study the reasonable proportion of PHES by utilizing mathematical programming method. Their research showed that the optimal proportion of PHES in power grid is 8%∼14% [4]. Worldwide, the proportion of PHES in Japan is 10.99%, 4.3% in E.U., 16% in Austria, 12% in Switzerland, 11% in Italy (All the data reflects the case in 2009). As the capacity of wind and solar power rising, the proportion of PHES in China will dramatically increase in the future. According to the government statistics [24], the PHES capacity will reach 33.67 GW, accounting for 3.7% of total installed capacity, in 2015, while the number will come up to 50.02 GW, accounting for 4.4%, in 2020. Relevant data can be seen in Table 3, although specific scheme has not officially been brought forward neither by government nor grid companies.

3. Management mode and price mechanism

As PHES developing rapidly in China, policy disagreement emerged on the aspects of management and price mechanism. For now, the main divergent viewpoint is not on whether to build, but on how to build and how to allocate the economic benefit on each investment entity. Until now, 4 management modes and 4 price mechanisms have been adopted in China, and there has not formed one unified mode for all PHES stations.

3.1. Management mode

3.1.1. Unified management pattern

In this mode, PHES station does not possess the status of legal personality, and the management authority of PHES property is power grid company-owned. Grid company is completely in charge of fund raising, station construction and operation management. For electricity price, grid company adopts one-part energy price interiorly, and finally get revenue though electricity sale price.

3.1.2. Independent management pattern (with one-part energy price)

In this mode, the station is qualified as independent management entity that can be regarded as legal personality. The one-part energy price is adopted as price mechanism, while the main difference from unified management pattern is that the feed-in tariff is formulated according to generating cost (including constant cost and variable cost) of PHES station. So the cost of PHES station is recovered by feed-in tariff based on its generated energy.

3.1.3. Two-part price pattern

In two-part price mode, the feed-in tariff is consisted of capacity part and energy part. Capacity payments mainly reflects the gross fixed cost which is closely relevant to the type of generating unit, initial investment, loan interest rate depreciation, etc. Energy payments mainly reflect the variable costs of PHES station which is relevant to pumping electricity price, material costs, etc. Two-part price pattern can be divided into independent management pattern and grid company-escrowed pattern. Compared to the independent pattern, the risk of grid company-escrowed pattern is relatively smaller because grid company has an advantage on making schedule plan for PHES station.

3.1.4. Capacity leasing pattern

Capacity leasing pattern also can be regarded as a special independent management pattern. Owner of PHES station leases the station to grid company to obtain rent which could cover the total cost, taxation expense, and reasonable return on investment. The station is uniformly scheduled by power grid Company as the grid company pays the rent. The rent is set by National Development and Reform Commission (NDRC), the government price department, according to current profit margin level and reasonable cost plus.

3.2. Price mechanism

As mentioned in 3.1.1, many price mechanisms are adopted in different management patterns. In this part, 4 price mechanisms are concluded briefly and their viability is analyzed.

3.2.1. Single energy-based price mechanism

In this mechanism, owner of PHES station gets revenue by feed-in tariff payed by grid company, and operation of the station to some extent is restrained to the dispatching conducted by grid company, making the station bear high operational risk, as the dispatching scheme cannot guarantee enough generation for PHES station. Since single energy-based price mechanism does not distinguish PHES station and regular power station, the capacity effects of PHES (peak shaving, voltage regulation,

emergency reserve, etc) is not mirrored adequately. This mechanism is suitable for early-stage constructed PHES station. At present, this mechanism is adopted by Huilong (in Henan province), Shisanling (in Beijing).

3.2.2. Two-part price mechanism

Two-part price is consists of capacity payments and energy payments. Revenue includes capacity fee and feed-in tariff. The separation of capacity payments and energy payments is designed to reflect the value of the ancillary services of PHES. This mechanism largely motivates investment to PHES station as it is characterized by low-risk with high-return. In the view of these advantages listed above, two-part price mechanism is normally appropriate to the rapid development phase of PHES when most PHES stations are not grid-incorporated and investment are facing financial situation. Only Tianhuangping (in Zhejiang province) station is representative of two-part price mechanism.

3.2.3. Single capacity-based price mechanism

In this mechanism, owner of PHES station rents the station to grid company to earn rental fee, which mainly depends on the station's capacity. In this way, the investment is sensitive to electricity price policy since it depends on whether grid company leases the station. Also this mechanism reflects the ancillary service function of PHES as the owner of the station can get stable payment according to station's capacity electricity fee. This mechanism is widely adopted by many PHES stations including Taian, Langyashan, Tongbai, Panjiakou, Yixing, Zhanghewan, Xilongchi, Baoquan, Baishan and Bailianhe.

3.2.4. T&D tariff mechanism

This mechanism is mostly adopted in the case of grid-dorminated PHES stations, where the station is regarded as grid company's equipment and property. Since PHES stations are invested and constructed by power grid company, government do not set feed-in tariff for PHES station alone, and the costs will be covered by the revenue charged from end users as T&D tariff. Examples for T&D mechanism are Pushihe, Xiangshuijian, Xianyou, Hongping and Xianju. All these stations were invested and operated by SGCC Xinyuan Corporation, a generation corporation founded by SGCC.

The trait and effect of each price mechanism is analyzed and compared in Table 4.

As for the price mechanism, Table 5 shows the data of price mechanism and price grooming situation of PHES stations, from which we can see that the single capacity price mechanism is being wildly adopted for the majority stations, while single energy price mechanism and two-part price mechanism (Tianghuangping station alone) are also exist.

3.3. SGCC

After discussing all the price mechanisms existing in China, it is important to provide a role model to analyze the operation and management characteristic of existing PHES. The role model is SGCC, which has been known as the most influential power grid company in China. The company also played an important role in leading the development of PHES as it is the biggest investment entity for many PHES stations. In March 2005, SGCC Xinyuan Co. was established as a subsidiary company of SGCC to take charge of the investment and operation of PHES station. As of 2010, SGCC Xinyuan Co. had an installed PHES capacity (wholly-owned

Table 4
Comparison of 4 price mechanism.

Price mechanism	Single energy-based price mechanism	Two-part price mechanism	Single capacity-based price mechanism	T&D tariff mechanism
Suited mode of investment	Joint investment	Joint investment	Joint investment	Proprietorship by grid company
Reflect ancillary service of PHES	No	Yes	Yes	Yes
Way to share electricity price	100% bear by customer side	100% bear by customer side	Shared by coal fired power station (25%), grid company (50%) and customer (25%)	100% bear by customer side
Adaptive phase and environment condition	Early-stage with relatively simple price management	Rapid development phase with financial strain	Immature market phase	Contestable market with independent transmission and distribution price mechanism

Table 5
Price mechanism of PHES stations (2009).

Name	Price mechanism	Price condition	Capacity utilized proportion
Tianhuangping	Two-part electricity price mechanism	Capacity price: ¥470/kW (Excl. Tax); Feed-in price: ¥0.4915/kWh (Excl. Tax); Pumping price: ¥0.3453/kWh (Excl. Tax)	Shanghai 42.9%; Jiangsu 28.6%; Zhejiang 19.0%; Anhui 9.5%
Huilong	Single energy electricity mechanism	Feed-in price: ¥0.85/ kWh (Inc. Tax); Pumping price: ¥0.214/kwh (Inc. Tax)	Anhui
Shisanling	Single energy electricity price mechanism	Feed-in price: ¥0.8/kWh; No pumping price	Beijing–Tianjin–Tangshan grid
Panjiakou	Single capacity electricity price mechanism	¥80,000,000 per year (Excl. Tax)	Beijing–Tianjin–Tangshan grid
Baishan	Single capacity electricity price mechanism	¥90,000,000 per year (Inc. Tax)	Jilin, Liaoning, Heilongjiang; The proportion has not determined yet.
Taishan	Single capacity electricity price mechanism	¥495,000,000 per year (Inc. Tax)	Shandong
Tongbai	Single capacity electricity price mechanism	¥484,000,000 per year (Inc. Tax)	Zhejiang 7/12; Shanghai: 5/12
Yixing	Single capacity electricity price mechanism	¥561,360,000 per year (Inc. Tax)	Jiangsu
Langyashan	Single capacity electricity price mechanism	¥267,710,000 per year (Inc. Tax)	Anhui: 50%; Shanghai: 50%
Zhanghewan	Single capacity electricity price mechanism	¥490,630,000 per year (Inc. Tax)	Hebei south grid
Xilongchi	Single capacity electricity price mechanism	¥531,670,000 per year (Inc. Tax)	Shanxi
Baoquan	Single capacity electricity price mechanism	¥507,460,000 per year (Inc. Tax)	Henan

or share contralled) of 11.47 GW, while 6.4 GW is under construction.

3.3.1. Investment entity

There are 18 PHES stations invested by SGCC Xinyuan Corporation, among which 4 stations were wholly invested by Xinyuan Co., while 14 stations were jointly invested by Xinyuan Co. and province power grid companies or local investment corporations. Langyashan, Xiangshuijian and Pushihe stations were even jointly invested by multi province power grid companies.

3.3.2. Price mechanism

For the stations which adopted two-part price mechanism (like Tianhuangping station) and single energy based price mechanism (like Huilong station), the stations' annual utilization hours could come up to 1000 to 1600 h, which basically guaranteed the profit of the stations.

We take Taian station as an example to analyze the situation of the stations which adopted single capacity-based price mechanism. Taian station was rented by Shandong Electric Power Corporation with 459 million RMB rental fee per year. In order to cover the costs, the electricity price for Taian station was set as 0.3947 RMB/kWh, while the price for coal-based generation in Shandong province was 0.3974 RMB/kWh. Obviously, the narrow price spread made Taian station's profit less reliable as the station cannot operate for enough hours in a year because of the high electricity price sold to power grid company. The same situation also went for Zhanghewan, Xilongchi stations under single capacity-based price mechanism. Therefore, these stations were generally functioned as reserve capacity for power system.

4. Barriers and advices on PHES

4.1. Geographical barriers

One of the most important roles of PHES is to compromise the intermittent wind power. As is well known that the joint operation of wind power and PHES can dramatically improve the stability of the power output, China's government also choose PHES as an optimal choice to solve the problem of gird integration of wind farms. However, the resources distribution is uneven. The wind resources are rich in north of China, like Sinkiang, Inner Mongolia and the northeast China, while the hydropower mainly scattered in east and southwest of China, like Yunnan and Sichuan province. Generally, there are thousands miles between PHES stations and large scale wind farms except several PHES stations (Huhehaote station is located in Inner Mongolia and Pushihe station is located in Jilin province).

4.2. Policy problems

4.2.1. Investment subjects are limited

In 2004, NDRC issued No. 71 document ([2004]71) which has always been regarded as guidelines of PHES development in China. No. 71 document specified that grid company, in principle, should be in charge of the construction and management of PHES stations and take responsibility of absorbing the cost (costs will be covered by sale prices through transmission and distribution prices), while generation companies are also entitled to invest and construct PHES stations.

Indeed, No. 71 document, to some extent, mitigated the wild situation of disordered investment of PHES for years. However, it also shut the door on many other subjects of investment at the same time. Currently, PHES investment market has almost entirely been monopolized by China's two grid companies-SGCC and CSPGC (China Southern Power Grid Company), and both of the two companies established specialized investment company (Stage Grid Xinyuan Company LTD and Peak and Frequency Modulation Company) to operate PHES stations, leaving a difficult investment circumstances for other entities.

In 2007, NDRC issued No.1517 document ([2007]1517), specifying that PHES stations that have been approved after No. 71 document need to be built entirely by grid company. What's more, unlike covering costs through transmission and distribution price, all the costs of construction and operation should be integrated into power grid operation cost. Obviously, document No.1517 decreased economic income of grid companies, who were entitled as the dominant subject of investment. As a result, the investing enthusiasm of grid companies was dramatically reduced and many preliminary work of PHES construction cannot gain support by grid companies, laying many PHES projects on the table. Currently, only few stations like Shahe, Tiantang and Heimifeng were invested and constructed by state investment companies or generating companies, a vast majority of PHES stations are grid-integrated. Detailed information can be seen in Tables 6 and 7.

4.2.2. Policy and price mechanism is deficient

So far, PHES-related policies and mechanisms are far from what is expected. Basically, there is no charging standard to reflect the function of PHES on the aspects of ancillary services like peak shaving, frequency modulation and emergency reserve. Furthermore, peak-valley tariff mechanism, in many places, has not yet been established or the price difference between peak and off-peak periods is insignificant (Normally, electric price in peak hours is 5 to 10 times higher than it in off-peak hours), which makes PHES stations, in some cases, pursue economic benefits by generating during peak hours. In addition, transmission and distribution price mechanism in power system is quite implicit because of the integration of power transmission and power distribution, result in the failure of cost recovery from customer sales prices.

4.3. Advices for policy makers

Considering the geographical barriers, the ultra-high voltage power grid may be a technically effective solution. As the high voltage (1000 kV AC of $\pm$800 kV DC) could transmit electric power thousands miles away, PHES stations and wind farms can be covered by power grids that have been inter-connected by ultra-high voltage transmission lines. Furthermore, the smart grid technology can also be used to control the joint operation of PHES and wind farms. As this paper is focused on mechanism and policy rather than technology, we will not discuss further on this problem.

Since the whole electricity price has not been marketized in China (the pricing power is exercised by government's price department), it is impossible to set PHES electric price alone by market rather than official department. So it is inevitable for the emergence of some operation management problems or mechanism bottleneck temporarily for PHES development as the government cannot concern on every possible complexity. Indeed, electricity price settled by government, for example the single capacity electricity price, do solve many dilemma for PHES stations that has been built, and some market mechanism can also stimulate the investment for PHES by generating companies and social capital. However, those practices also increased the overall electricity price level and trigger new contradiction as regional benefit gap would occur among PHES stations. Taking all these factors into consideration, we suggest that PHES should continue to be operated and scheduled by grid companies in terms of exertion of its positive effects. Meanwhile, at the fast

Table 6
Detailed information of PHES stations in operation.

Region	Province	Name	Capacity (MW)	Investment holder
North China	Beijing	Shisanling	800	SGCC Xinyuan Co.
	Beijing	Miyun	22	Local Gov.
	Hebei	Zhanghewan	1000	SGCC Xinyuan Co.
	Hebei	Gangnan	11	Local Gov.
	Hebei	Panjiakou	270	SGCC Xinyuan Co.
	Shanxi	Xilongchi	1200	SGCC Xinyuan Co.
	Shandong	Taian	1000	SGCC Xinyuan Co.
East China	Jiangsu	Shahe	100	Juangsu Guoxing investing Co.
	Jiangsu	Yixing	1000	SGCC Xinyuan Co.
	Zhejiang	Tongbai	1200	SGCC Xinyuan Co.
	Zhejiang	Tianhuangping	1800	SGCC Xinyuan Co.
	Zhejiang	Xikou	80	Electric Power Development Co.
	Anhui	Langyashan	600	SGCC Xinyuan Co.
	Anhui	Xiangshuijian	80	SGCC Xinyuan Co.
Central China	Henan	Huilong	120	SGCC Xinyuan Co.
	Henan	Baoquan	900	SGCC Xinyuan Co.
	Hubei	Tiantang	70	Hubei Minyuan development Co.
	Hubei	Bailianhe	1200	SGCC Xinyuan Co.
	Hunan	Heimifeng	600	CLP Group
	Sichuan	Cuntangkou	2	Electric power Co.
Northeast China	Jilin	Baishan	300	SGCC Xinyuan Co.
West China	Tibet	Yangzhuoyong Lake	90	Electric power Co.
South China	Guangdong	Guangzhou	2400	CSPGC
	Guangdong	Huizhou	2100	CSPGC
Total			16,945	

Table 7
Detailed information of proposed PHES stations.

Region	Province	Name	Capacity (MW)	Investment holder
North China	Shanxi	Xilongchi	1200	SGCC Xinyuan Co.
East China	Jiangsu	Liyang	1500	Juangsu Guoxing investing Co.
	Anhui	Xiangshuijian	1000	SGCC Xinyuan Co.
	Anhui	Foziling	160	Anhui Kongyuan Co.
	Fujian	Xianyou	1200	SGCC Xinyuan Co.
	Zhejiang	Xianju	1500	SGCC Xinyuan Co.
Central China	Henan	Baoquan	300	SGCC Xinyuan Co.
	Hunan	Heimifeng	600	CLP Group.
	Jiangxi	Hongping	1200	SGCC Xinyuan Co.
Northeast China	Liaoning	Pushihe	1200	SGCC Xinyuan Co.
	Inner Mongolia	Hohhot	1200	Province grid company
South China	Guangdong	Huizhou	300	CSPGC
	Guangdong	Qingyuan	1280	CSPGC
	Guangdong	Shenzhen	1200	CSPGC
Total			13,840	

developing stage, governments should also take its responsibility to subsidize on the stations' operation, including explicit subsidies on feed-in tariff and the intermittent implicit subsidies during its operation, to relieve the price pressure of the ever-growing integration of renewable energy.

5. Conclusions

This review papers details and presents the status of development of China's PHES, including the capacity, locations of existing and proposed PHES stations. We can see that PHES in China will enjoy next 10-year prosperous development as large-scale renewable energy integrating in to power grid. Also, PHES is facing great challenges on it management and operation mechanisms. In order to get through the transitory stage, we suggest that operation of PHES should be temporarily managed by grid company and government should give great capital support on PHES development.

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